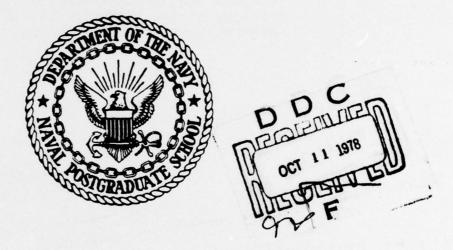


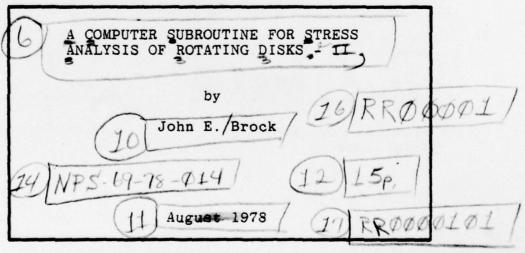


NPS-69-78-014

NAVAL POSTGRADUATE SCHOOL

Monterey, California





Approved for public release; distribution unlimited.

Prepared for:

Chief of Naval Research Arlington, Virginia 22217

251 450

NAVAL POSTGRADUATE SCHOOL Monterey, California

Rear Admiral Tyler Dedman Superintendent

J. R. Borsting Provost

A COMPUTER SUBROUTINE FOR STRESS ANALYSIS OF ROTATING DISKS - II

This report corrects errors in a previous report on the same subject and presents a listing of a revised and improved digital computer program for finding stress distribution in a thin rotating disk with nonuniform heating.

ofessor of Mechanical

Engineering

Approved by:

Mechanical Engineering

Department

Dean of Research

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Date Entered)

REPORT DOCUMENTATION PAGE	READ INSTRUCTIONS BEFORE COMPLETING FORM		
NPS-69-78-014	3. RECIPIENT'S CATALOG NUMBER		
A COMPUTER SUBROUTINE FOR STRESS ANALYSIS	S. TYPE OF REPORT & PERIOD COVERED		
OF ROTATING DISKS - II.	6. PERFORMING ORG. REPORT NUMBER		
7. AUTHOR(e)	8. CONTRACT OR GRANT NUMBER(*)		
John E. Brock			
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT, PROJECT, TASK		
Professor John E. Brock (Code 69Bc) Department of Mechanical Engineering	61152N, RR000-01-01 N0001478WR80023		
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE		
Naval Postgraduate School Monterey, California 93940	August 1978 13. NUMBER OF PAGES 12		
14. MONITORING AGENCY NAME & ADDRESS(II dillorent from Controlling Office)	18. SECURITY CLASS. (of this report)		
Chief of Naval Research	Unclassified		
Arlington, Virginia 22217	134 DECLASSIFICATION/DOWNGRADING		
16. DISTRIBUTION STATEMENT (of Inte Report)			
Approved for public release; distribution	unlimited.		

17. DISTRIBUTION STATEMENT (of the obstreet entered in Block 20, If different from Report)

18. SUPPLEMENTARY NOTES

18. KEY WORDS (Continue on reverse side if necessary and identity by block number)

Stress analysis Rotating disks, Heated Disks Axisymmetric Elasticity, Axisymmetric Disks, Elastic Disks

20. ABSTRACT (Continue on reverse side if necessary and identity by block number)

This report corrects errors in a previous report on the same subject and presents a listing of a revised and improved digital computer program for finding stress distribution in a thin rotating disk with nonuniform heating.

A Computer Subroutine for Stress Analysis of Rotating Disks - II.

by John E. Brock

Based upon theory developed by the writer, R. E. Brown developed a successful computer program for analysis of radial and circumferential stresses in rotating axisymmetric disks of variable thickness having an axisymmetrical thermal strain field. The writer revised Brown's program so as to invoke a group of ancillary subroutines which have been found useful in another application. In doing so, however, much unnecessary and confusing normalization was introduced. In particular, one of the normalizations would cause the analysis to fail in the quite common case of a disk with no radial loading at its outer boundary. All this material appears as Reference 1, hereof.

Referees evaluating a paper based upon Reference 1, called attention to these faults so that the program has been rewritten. A listing of the main subroutine, RODISK, as revised, as well as listings of the ancillary subroutines may be found in Appendix A hereof. The reader will note that other changes have also been made resulting in somewhat more flexibility of application. Employment of the revised program is described in the textual material which appears at the beginning of the listing.

Appendix B contains a revision of the second illustrative example problem of Reference 1. This problem was solved for various values of M = N-1, the number of equal subdivisions into which the annular radius b-a is divided for purposes of numerical analysis by RODISK. Also, a

number of different values of KP(3) were used. If KP(3) > 0, its value is the number of iterations which will be performed by RODISK. If KP(3) < 0, iteration will continue until three successive values of the unknown parameter B determined in the course of the analysis, satisfy the relation

$$\frac{|B_1-B_2| + |B_2-B_3| + |B_3-B_1|}{|B_1| + |B_2| + |B_3|} < 10^{KP(3)}$$

We also determined execution time by use of the library subroutine IXCLOK, executing under CP-cms on the IBM 360/67 at the W. R. Church Computer Center at the Naval Postgraduate School.

We found that execution time per iteration is

for any problem.

Accuracy was evaluated by dealing with problems having available analytic solutions. It was found that the principal limitation on accuracy is determined by the choice of subdivions, the integer M = N-1, so that there is a certain inherent error regardless of how many iterations are made. This error depends on M, of course, and upon the details of the problem. The error is greatest near the inner radius of an annular disk, and is large if the ratio a/b is small. Fortuitously, the error may be smaller for an early iteration than for a somewhat later iteration but this is not practically useful information. For the problem of Appendix B hereof, with a/b = .165, we find the results given in Table 1, (see next page).

Thus, for example, with M = 20, there is an inherent error of about 1% and the results are not significantly improved by iterating

approx. limiting ferror	approx. iters. req'd.	total time, secs.		
16	5	.055		
5	7	.12		
1	11	.32		
.1	17	.90		
.01	25	3.1		
	limiting # error 16 5 1	limiting iters. % error req'd. 16 5 5 7 1 11 .1 17		

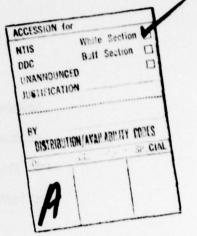


Table 1. Percent error, required iterations, and execution time for problem of Appendix B.

more than eleven times. With eleven iterations, the solution is returned from RODISK in 0.32 seconds.

The significant conclusion is that the execution is so fast that one may as well take M = 100 (corresponding to N = 101, the maximum available under present dimensioning) and iterate many more times than is strictly necessary. Taking N = 101 and $\mathrm{KP}(3)$ = -8 gave execution in 3.7 seconds with 31 iterations and with an accuracy of 0.004% (In the problem at hand, $\sigma_{\mathrm{P}}(a)$ was specified as zero and the program gets -1.14E-11 so that the error here is "infinite". Our evaluation of 0.004% is for the first position rather than for the zeroeth.)

This concludes the text proper of the present report. However, we take advantage of this opportunity to correct errors in Reference 1, viz.:

(1) Page 3, equation 12 should read

$$m = \pm \sqrt{(n^2 - 4\nu n + 4)} = \pm \sqrt{(n-2)^2 + 4(1-\nu)n}$$

- (2) Page 6, line 2. In place of T read aT.
- (3) Page 6, equation 33. Lower limit of integration should be a rather than 0.
- (4) Page 7, line following equation 40. Reference should be to equation 37 rather than equation 38.

Acknowledgment is gratefully made for assistance by the Naval Post-graduate School Research Foundation. Appreciation is also expressed to the referees of the ASME Journal of Applied Mechanics for directing attention to the flaws in the earlier version of RODISK.

REFERENCE

 Brock, J. E., and Brown, R. E., A computer subroutine for stress analysis of rotating, heated disks. NPS-69-78-012, Naval Postgraduate School, Monterey, California, May 1978 Appendix A
Listing of
Subroutine
RODISK
and ancillary
subroutines

```
SUBROUTINE RODISK. JOHN E. EROCK, I MAY 1978, FEVISED I AUGUST 1978, FILE IS A SUBROUTINE FOR DETERMINING PROBLEM OF CIRCUMPRICE THERMALESS RESERVED IN AN ALL SYMMETRIC THERMALESS RESERVED RESERVED AND ROTATING AT ANGULAR VELOCITY OMEGA (FACILY SYSECOND) RESERVED RESERV
```

THIS PAGE IS BEST QUALITY PRACTICABLE FROM COPY FURNISHED TO DDC

```
FEAL *8 X(30,101)

INTEGER NOTS:

COMMON VINEY RADOLS ALS RAPPOLS ARE SEVERAL ANCILLARY

SUBACUTINES AND ROTHER WARLES AND SERVICES THE STRUCTURE

THE VALVE ARE SOCIOUS IN THE USA'S MAIL PRECEDED TO THE PRINT A VECTOR LARS NOT SERVICES AND SERVICES AND
```

THIS PAGE IS BEST QUALITY PRACTICABLE FROM COPY FURNISHED TO DDC

```
00 1 **!.N

X (N2.1) **X (N1.1) **S

RITURN

SUBROUTINE CIVS(N1.N2.S)

REAL***A X(20.101).3

1 X(N2.1) **X(N1.1) / S

RETURN

INTEGER **P(5)

COMMON X.N. KP

1 X(N2.1) **X(N1.1) / S

RETURN

SUBROUTINE PRIV (N1.I.J)

REAL**B X(20.101).3

INTEGER **P(5)

COMMON X.N. KP

IF SECOND ARGUMENT SCUALS 0. GO DIRECTLY TO RETURN

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR. ITY AND THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY OF THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY OF THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY OF THE VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND VECTOR.

IF SECOND ARGUMENT SCUALS 1. PRINT THE VECTOR ITY AND V
                                                                                                                                                                                                                                                                                                                                                                                                                                                O. GO DIRECTLY TO RETURN

1. PRINT THE VECTOR.

2. PRINT THE USENTITY AND THE VECTOR.

3. PRINT THE VECTOR NUMBER AND THE VECTOR.

4. PRINT NUMBER: IDENTITY, AND VECTOR.

5. PRINT IDENTITY ONLY.
```

0000

```
5 WFITE [6,51] J. VECTOR WITH IDENTITY ',15,' HAS EEEN GENERATED.')

FOR COUTING COUPY (NI, N2)

ENDOUTINE OUPY (NI, N2)

RECUCE TO COUPY (NI, N2)
```

- 9 -

Appendix B

Sample Problem

A disk rotating at 7200 rpm and composed of a metal having a a specific weight of 0.283 pounds per cubic inch, is 0.85 inches inside diameter and 5.15 inches outside diameter. The radial stress at the inside radius is zero and that at the outside radius is 22,000 psi. The thickness varies with radius according to the law

t = $0.1493 \text{ r}^{-0.42}$ (all dimensions in inches) and the temperature change (from the zero stress condition) is given by T = $60 - 1.6 \text{ r}^2$.

Take E = 29,000,000 psi and α = 6.7 10^{-6} /°F and determine radial stress ($\sigma_{\rm p}$) and circumferential stress ($\sigma_{\rm e}$) as functions of r.

This problem illustrates most of the capabilities of RODISK. Because of the special nature of the thickness variation, i.e, a power relation, an analytic solution may be established so that the accuracy of the RODISK solution may be evaluated. Results of such evaluations are given in Table 1 of the body of this report. There it may be seen that accuracy far better than engineering considerations require or justify may be obtained by taking, say, N = 101 and KP(3) = 25, so that in 3.1 seconds RODISK returns to the calling (i.e., input) program results with a maximum error of 0.01 % or less. The tabulation which follows shows output with N = 101 and KP(3) = -6, resulting in 27 iterations and taking 3.3 seconds. Accuracy is better than .006%.

RODISK PROBLEM OF TYPE I

27 ITERATIONS REQUIRED WITH EPSILON = 1.00-6

						_					
SMF.	8	8	9	9	8	9	9	9	9	9	04
IGMA CIRCUMF	3.264550 04	2.404890 04	2,174160 04	2,123880 04	320	2.195150 04	2.264270 04	2.343820 04	.430400	.522260 04	2,618480 04
A	264	404	174	123	143	195	264	343	430	522	618
100	3	2	2	2.	2.	2.	2.	2.	2.	2	2.
S											
IAL	-12	9.848780 03	9	9	1.820550 04	8	9	8	8	9	9
IGMA RADIAL	2,275920-12	780	.41231D 04	.657790 04	550	8	.023940 04	065680	.138970	175110	.200000
A A	275	348	112	125	320	337)239	680	386	175	2002
0	2.7	9.6	-	-		-	2.0	2.0	2.1	2.	2.
0,											
EE	04	04	04	9	03	03	03	03	03	03	03
4	40	.114870	.074900	.023430 04	0.60467D	3,860080 03	3.000530	.026010	33	.732090	06
a d	433	148	749	234	046	009	000	260	.936530	320	.412690
EA	1.143340 04	=	-	0.	9.6	8.8	8.0	7.0	5.9	4.7	3.4
w											
8	02	05	02	02	02	02	05	05	02	05	02
THICKNESS GAMMA OMEGA	800	4.168800	.168800	1.168800	4.168800	80D	4.168800	1.168800	006691.1	1.168800	1.168800
3	4.16880D	168	168	168	168	1.16880D	168	168	691	168	168
M	4	4	4	4	4	4	4	4	4	4	4
SA											
553	8	8	8	8	8	0	8.896850-01	0	0	0	0
Z	.598470 00	.345960	. 191790	.08464D 00	260	30	350	8.466290-01	330	78044D-0	.500680-0
H	186	3459	6	1846	104	=	396	199	5860	804	900
	-	_	-	-	-	9.4	8.8	8.4	8.0	7.7	7.5
	ō	8	8	8	8	8	8	8	8	8	8
RAD	8	900	900	8	90	8	900	8	000	8	900
-		0	7	×	8	8	ŏ	ŏ	8	3	S
	800	88	5	4	27	8	5	98	6	12	5
	8.500	1.280	000017.1	2.140000	2.570000	3.000000	3.430000	3.860000	4.29000	4.72000	5.15000
	8.500	1.280	1.710	2.140	2.57	3.00	3.43	3.86	4.29	4.72	5.150

Figure 1. Typical output (for sample problem). The main program supplied information about inner and outer radii and the rdial stressese thereat, anywlar velo-The main program also supplied N = 101, v = 0.3, KP(1) = 1, KP(2) = 10, KP(3) =city and density, and "EE ALPHA TEE." These data reappear in the output above. -6, KP(4) = 0, and KP(5) = 0. Then it called subroutine RODISK which produced the output shown here. Execution time was 3.3 seconds.

INITIAL DISTRIBUTION LIST

1.	Defense Documentation Center Cameron Station Alexandria, VA 22314	2
2.	Library Naval Postgraduate School Monterey, CA 93940	2
3.	Dean of Research, Code 012 Naval Postgraduate School Monterey, CA 93940	1
4.	Chairman Department of Mechanical Engineering Naval Postgraduate School Monterey, CA 93940	1
5.	Professor J. E. Brock, Code 69Bc Naval Postgraduate School Monterey, CA 93940	15
6.	LCDR Robert E. Brown, USN Naval Amphibious School Coronado San Diego, CA 92155	2
7.	Mr. Charles Miller	1.
	NAVSEA Code 0331 Naval Ship Systems Command Washington, DC 20362	
8.	Mr. Richard Carleton NAVSEC Code 6146 Naval Ship Engineering Center Washington, DC 20362	1